FINAL TECHNICAL REPORT FOR NAG 5-599
August 31, 1990

This is the final technical report for the grant NASA NAG 5-599 "Ultraviolet Observations of Astronomical Source" covering the period September 1, 1985 through August 31, 1990. This grant supported studies of cool stars that are members of binary systems and studies of the properties of single cool stars. This work was coordinated with that under a grant to Hollis R. Johnson of Indiana University (NAG 5-182) for the study of cool giant stars in the ultraviolet. During the course of this grant, the PI was a research scientist at Indiana University. He moved to Tennessee State University in fall 1989, with the grant continuing at IU through a one-year no cost extension. Several of the research projects discussed here are continuing at TSU.

Observations were obtained with the long wavelength camera of IUE to investigate the gravity darkening of W UMa-type contact binaries. These are double stars so close to one another that they are enclosed in a common outer envelope. The envelope somehow transfers energy from the more massive component to the less massive component, perhaps by acting as a giant convection cell. The gravity darkening is a measure of whether the envelope is convective and whether its structure is altered by the energy transfer. Data for V566 Oph (Eaton 1986b) showed that the common envelope in this early F-type system is clearly low, hence convective. Data for W UMa and SW Lac (Eaton 1986a), two much cooler systems, were also consistent with convective gravity darkening (as expected), but the wavelength dependence of the light variation required at least one of the stars to have a very peculiar energy distribution, and it was suggested this may be an indication of lots of small spots or of some peculiar mode of convection. Observations were obtained for V535 Ara, an even hotter W UMa binary to investigate the dependence of gravity darkening on effective temperature (Eaton 1990c). Optical and ultraviolet colors and the ultraviolet spectra were used to classify the system A8 V. A light curve formed from the 46 LWP spectra showed complications completely like those previously seen in the optical by Chambliss and Schöffel, and this has confused the analysis. However, the observations were best explained by a hotter than expected inner face on the more massive binary component. The gravity darkening in this system is also probably convective, and this suggests that W UMa binaries must likely be convective in order to transport energy efficiently in their common envelopes.

Two binaries with 96-day periods (5 Cet and UU Cnc) both seem to be semi-detached systems with a K giant star filling its Roche lobe. IUE observations at both high and low dispersion for 5 Cet (Eaton and Barden 1988) show the results of this structure, with a hot secondary component detected in the ultraviolet. The source is most likely a disk because of its color, its random light variations, and a spectrum consisting of broad Fe II lines superimposed on the emission (also Eaton 1988b). Interestingly enough, solution of the optical light curve, with measured rotational velocity $v \sin i$ used as a constraint, shows

the K giant is more massive than its hot companion and should be unstable to rapid mass transfer. So far, catastrophic mass transfer has hot materalized. IUE data were obtained around the orbit of the 96-day binary UU Cnc (Eaton 1990b) to search for emission of a hot secondary component (not found), for effects of variable accretion onto the secondary (not found either), and for an atmospheric eclipse by or of the secondary (inconclusive). These data were combined with ground-based photometry and very limited high-dispersion spectroscopy to derive a mass ratio and geometrical properties of the system. (Further unrelated ground-based data have sharpened this picture.) The system seems to consist of a K4 II star in contact with its Roche lobe spilling material onto a G giant. The mass ratio of this semi-detached system is near 1.2, with the mass loser being less massive. Again, this should leave the system dynamically unstable to mass transfer, but it does not seem to be so.

Much of the effort in this grant was spent on understanding the properties of cool stars' chromospheres deduced from eclipses of ζ Aur binaries. An extensive analysis of archival IUE observations of 31 Cyg (Eaton 1987b,1988c), utilizing synthetic spectra, was carried out, and this led to measurements of physical properties of the chromospheric gas–temperature, ionization, and electron density as a function of height above the photosphere. Calculations for a follow-on study of 31 Cyg have been made which investigate the possibility of systematic errors in the turbulence. Also, extensive preliminary calculations for a study of 32 Cyg have been made. These consist of a grid of theoretical spectra showing how the many lines seen in atmospheric eclipses of ζ Aur binaries change in strength with changing values of parameters such as mass column density, excitation temperature, and turbulent velocity. These calculations cover the wavelength ranges 1180-1950 Å and 2500-3100 Å. The grid now covers the range 10^{-5}gm/cm^2–15 gm/cm^2 in column density of absorbers, 10-30 km/s in microturbulent velocity, and at least two temperatures for each column density. A study, based on this grid, of the changes in low-dispersion IUE spectra with properties of chromospheric gas was presented at the Sixth Cambridge Workshop (Eaton 1990a).

In other studies of ζ Aur binaries, monitoring of 31 Cyg at phases far from eclipse was started to provide a record of the behavior of wind lines to be compared with data from the upcoming eclipse of 1993. Observations of δ Sge, a ζ Aur binary containing a bright M giant, were started during this time. Extensive IUE observations were also obtained for the 96-day southern system AL Vel (Eaton 1989; Eaton, Kondo, McCluskey, and Shore 1990), a low-luminosity ζ Aurigae binary containing a bright K0 giant. This system has the distinction of being the closest ζ Aur binary, and the interaction of the K0 III component's wind with the B8 V star is considerable. The wind was found to be highly phase dependent, at least in its ability to show up in ultraviolet spectra. At most phases it is ionized by the B star in a rather large zone in the vicinity of the two stars. Thus, it shows up only weakly in the usual absorption lines such as Mg II and Fe II. However, it strengthens greatly near the eclipse of the B star, when it it shielded from ionization by the K star's chromosphere. This has complicated our analysis of the eclipse by making the low-dispersion spectra, especially the LWP ones, useless for studying the *chromospheric*

eclipse. Nevertheless, two high-dispersion LWP spectra made it possible to analyze the gas very high in the chromosphere and to derive a rough excitation temperature for one of the lines of sight.

Archival low-dispersion long-wavelength IUE spectra were used to determine how the ultraviolet emissions of stars later than A0 changes with spectral type (Eaton 1987a). Colors were formed from these spectra that measured the strength of UV features such as the Fe II break at 2630 Å, the UV continuum vs. the V magnitude, and the Mg II h and k emission vs. V magnitude. These colors show a well defined dependence on spectral type which can be used for classifying stars more reliably and for identifying stars with peculiar spectra. They have been used in numerous subsequent studies of cool stars. Synthetic spectra have been calculated for comparison with some of these observations (Eaton 1986c).

Three years of observations LWP spectra were obtained to investigate the chromospheric variability of semiregular variable M giants (Johnson and Eaton 1989; Eaton, Johnson, and Cadmus 1990a,b). Most of these were low dispersion exposures for θ Aps, NU Pav, and W Cyg. Limited high-dispersion observations were made of R Lyr and δ^2 Lyr, as well. For both W Cyg and θ Aps, the Mg II emission was rather well correlated with the star's optical and UV brightness, indicating the chromosphere is excited by the general transfer of energy through the star. The best data were for W Cyg, for which Cadmus has obtained extensive BV photometry. In it, there was a pronounced phase shift between the optical (and also 2600-3200 Å) continuum and Mg II h and k strength, indicating that changes in luminosity must propagate upward through the chromosphere before they excite it observably. Data for NU Pav are somewhat less well correlated with the continuum, but NU Pav has a much higher level of chromospheric emission for its luminosity, and other processes, which do not affect W Cyg and θ Aps, may be important.

A list of the papers published or written under this grant and referred to above is attached.

PUBLICATIONS USING IUE DATA

Eaton, J.A. 1986a, "SW Lacertae, W Ursae Majoris, YY Eridani, and the Prevalence of Starspots in Cool Contact Binaries," *Acta Astr.*, **36**, 79.

Eaton, J.A. 1986b, "Implications of the Light Curve of the A-Type W UMa binary V566 Ophiuchi," *Acta Astr.*, **36**, 275.

Eaton, J.A. 1986c, "Synthetic Spectra of Cool Stars for Wavelength Range 2550-3200 Å," in *New Insights in Astrophysics* ed. E. J. Rolfe (ESA SP-263), p. 141.

Eaton, J.A. 1987a, Ultraviolet Photometry with the IUE Satellite," in *New Generation Small Telescopes, Proc. Eighth Annual Fairborn I.A.P.P.P. Symposium*, ed. D.S. Hayes, D.R. Genet, and R.M. Genet (Mesa, AZ: Fairborn Press), p. 411.

Eaton, J.A. 1987b, "Synthetic Eclipse Spectra for 31 Cyg," in *Proc. Fifth. Cambridge Workshop*, ed. J. L. Linski and R. E. Stencel, p. 329.

Eaton, J.A. 1988a, "Light Curves of Contact Binaries and the Energy Transfer Mechanism,"in *Close Binary Systems: Theories and Critical Observations* (Gordon and Breach), p. 227.

Eaton, J.A. 1988b, "Ultraviolet Fe II Absorption Lines in HD 59643," in *IAU Colloq. No.103, The Symbiotic Phenomenon* ed. J. Mikolajewska, M. Friedjung, S.J. Kenyon, and R. Viotti (Dordrecht: Kluwar), p. 25.

Eaton, J.A. 1988c, "The Atmospheric Eclipse of 31 Cygni in the Ultraviolet," *Ap. J.*, **333**, 288.

Johnson, H.R., Eaton, J.A., Querci, F., Querci, M., and Baumert, J.H. 1988, "The Unusual Carbon Star HD 59643: Alternative Models," *Astr. Ap.*, **204**, 149.

Eaton, J.A., and Barden, S.C. 1988, "The Long-Period Semi-Detached Giant Binary 5 Ceti," *Acta Astr.*, 38, 353.

Johnson, H.R., and Eaton, J.A. 1989, "Spectrophotomertry of Late M Giants with IUE," in *New Directions in Spectrophotometry*, ed. A. G. Davis Philip, D. S. Hayes, and S. J. Adelman (L. Davis Press), p. 213.

Eaton, J.A. 1989, "The Long Period Binary AL Velorum," in *Remote-Access Automatic Telescopes*, ed. D. S. Hayes and R. M. Genet, (Mesa, AZ: Fairborn Press), p. 203.

Eaton, J.A. 1990a, "Ultraviolet Extinction in Zeta-Aurigae Binaries at Low Resolution," in *Sixth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun*, ed. G. Wallerstein, (San Francisco; Astr. Soc. Pacific), p. 246.

Eaton, J.A., Johnson, H.R., and Cadmus, R.R. 1990a, "Chromospheric Variability of M-Giant SR Variables," in *Sixth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun*, ed. G. Wallerstein, (San Francisco; Astr. Soc. Pacific), p. 488.

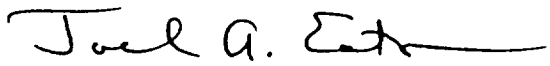
Eaton, J.A. 1990b, "The long-period binary UU Cancri as a system that has reversed its mass ratio," *M.N.R.A.S.*, in press.

Eaton, J.A., Johnson, H.R., and Cadmus, R.R. 1990b, "Chromospheric Variability of M Giant Semiregular Variables," *Ap. J.*, in press, Nov. 20th issue.

Eaton, J.A., Kondo, Y., McCluskey, G.E., and Shore, S.N. 1990, "The Long Period Binary AL Velorum: The Atmospheric Eclipse of a Bright K0 Giant" *A. J.*, in press, Sept. 1990.

Eaton, J.A. 1990c, "Ultraviolet Light Curves of V535 Arae," *Ap. Space Sci.*, in preparation.

Respectfully Submitted,



Joel A. Eaton
Principal Investigator